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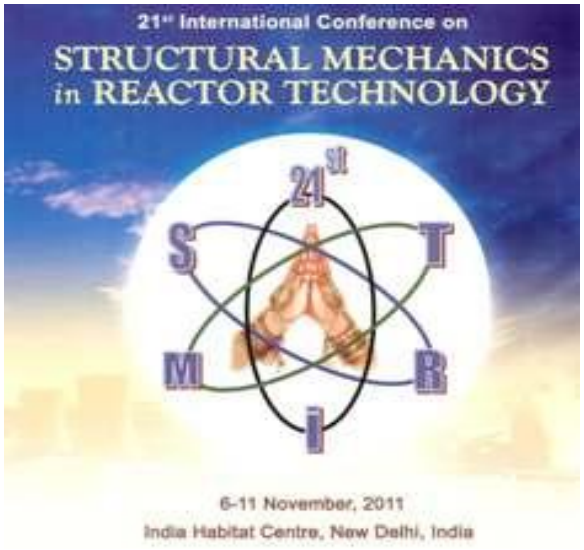
Reinforced Concrete Supporting Pad Design for an Independent Spent Fuel Storage Installation (ISFSI) and Seismic Soil Structure Interaction (SSI)



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What is Soil Structure Interaction (SSI)?

- The process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is termed as soil-structure interaction
- Structure subjected to an earthquake excitation, interacts with the foundation and the soil, and thus changes the motion of the ground
- SSI can be divided into two phenomena:
  - Kinematic Interaction
  - Inertial Interaction

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SSI Models for Nuclear Structures

- Most soil-structure interaction analyses at commercial Nuclear Power Plant (NPP) have focused on the effect of the foundation on the response of site buildings affixed to ***rigid*** foundation mats
- As such, SSI analysis has been performed using linear elastic models for the structure above the mat and layered continuum models for the soil under the mat

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Rigid Vs. Flexible Support Pad

- With the increased focus on siting dry storage facilities at nuclear plants, it is necessary to revisit traditional SSI analysis used for the support pad
- In view of recent large seismic events there appears to be a need to extend the SSI methodology to include ***non-rigid (flexible)*** mats, such as ISFSI support pads
- In USA the ISFSI pads are designed per the regulatory requirements of Code of Federal Regulations - 10 CFR Part 72

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Linear Vs. Non-linear Behavior

- The non-linear behavior of a typical large free-standing dry storage cask emplaced on an ISFSI pad (flexible) behaves quite differently than a traditional massive shear wall type of structure commonly used for the “power block” buildings at NPPs
- The dry storage casks may lift, rock, precess, slide, or tip over depending on the severity of the seismic event

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Traditional SSI Analysis

- Developments in the technique of:
  - computational modeling (in the time domain)
  - modeling of the vertical springs to model the upper, best and lower bounds of the soil supporting the pads
  - dynamic soil properties including profile layering
  - strain-compatible soil properties, and other non-linear dynamic analysis related details

  These have been well established components of SSI analysis for over 20 years

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Non-linear Dynamic Analysis of ISFSI PAD

- SSI analysis techniques need to be further enhanced to include flexible pads such as ISFSI concrete pads
- These pads are typically simple reinforced concrete mat foundation, 2'-0" to 3'-0" thick, rectangular in shape, and collocated at the reactor site, storing anywhere from 20 ~ 90 casks
- The fact that free standing storage casks (simply resting) on the ISFSI pad could slide or tip, adds a true non-linear components to the SSI analysis resulting in far more complex problem than a typical SSI analysis

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ISFSI Pad on a Flexible Foundation

- SSI problems involve the determination of the response of structures on a flexible soil foundation system
- The interaction effects related to the stiffness of the structure is known as the kinematic interaction. The mass related effects are called the inertial interaction
- Regardless of whether the pad is rigid or flexible founded on a soil or on a rock site, the control motion is specified at the control point either at the ground surface or rock outcrop by a response spectrum and its associated time-histories

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CLASSI and SASSI

- If the foundation is rigid either a soil spring model with a stick model super-structure (time domain analysis) or A Linear Continuum Mechanics Approach (CLASSI) model with a stick model super-structure (frequency domain analysis) can be used
- If the foundation is flexible, either a Structural Analysis Software System Interface (SASSI) analysis (frequency domain) or an Livermore Software for Dynamic Finite Element Analysis LS-DYNA analysis (time domain) can be used

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SSI - Finite Element Method - Substructure Method

- The substructure methods involve:
  - Site response analysis
  - Foundation scattering analysis
  - Foundation impedance analysis
  - Modeling of the structure and solving for the SSI problem

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Steps to perform SSI

- The site response analysis determines ground motion within the supporting soil medium
- The scattered motion, if applicable, may include rocking and torsional components in addition to translational motion
- The foundation impedance analysis determines the foundation spring and the damping coefficients
- With all the above information the structural dynamic model and the final solution of the equations of motion are developed that can be used for the actual design of the foundation mat

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US NRC SRP - NUREG 0800 (Excerpts)

- Standard Review Plan (SRP) - NUREG 0800, Chapter 3.7, stipulates that SSI analyses be performed using a range of soil properties
- Three different sets of shear and compression wave velocity profiles should be developed
- The best-estimate velocity profile and the high and low velocity profiles shall be used
- Strain compatible soil properties shall be used
- Seismic accelerations shall be amplified from rock level to structure foundation level

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Summary – ISFSIs and Effects of SSI

- If the seismic ground motion is not sufficiently high to cause the cask to lift off the pad or slide on the pad, the cask behaves essentially as if it were bonded to the pad
- After the cask begins to tip, it is no longer valid to assume that the cask is bonded to the pad
- Once an edge of the cask lifts up from the pad, the frequency of that rocking motion becomes a highly nonlinear function of the amplitude of that motion
- This can be a significant energy dissipation mechanism, and the type of soil underlying the pad can have a noticeable effect on the amount of energy

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Envisioned Path Forward

- At US NRC/NMSS there are plans to prepare a Regulatory Guideline (RG) for the Design/Analysis of ISFSI concrete support pads, addressing issues such as:
  - **Seismic Soil-Structure Interaction (SSI) Analysis**
  - **Linear Methods**
  - **Soil Spring Models - ASCE Standard 4-98 [Future ASCE-4-2012]**
  - **Developing Strain Compatible Soil Properties**
  - **Frequency Domain Methods (SASSI)**
  - **Incorporating Pad Flexibility**
  - **Non-Linear Methods for Cask Rocking and Sliding**
  - **Coupled Analysis Methods (LS-DYNA)**
  - **Decoupled Analysis Methods**
  - **Linear SSI Analysis**
  - **Non-linear Sliding and Rocking Analysis**
  - **Time-History Analysis**
  - **ASCE Standard 43-05 Appendix A Method**

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Questions From the Audience